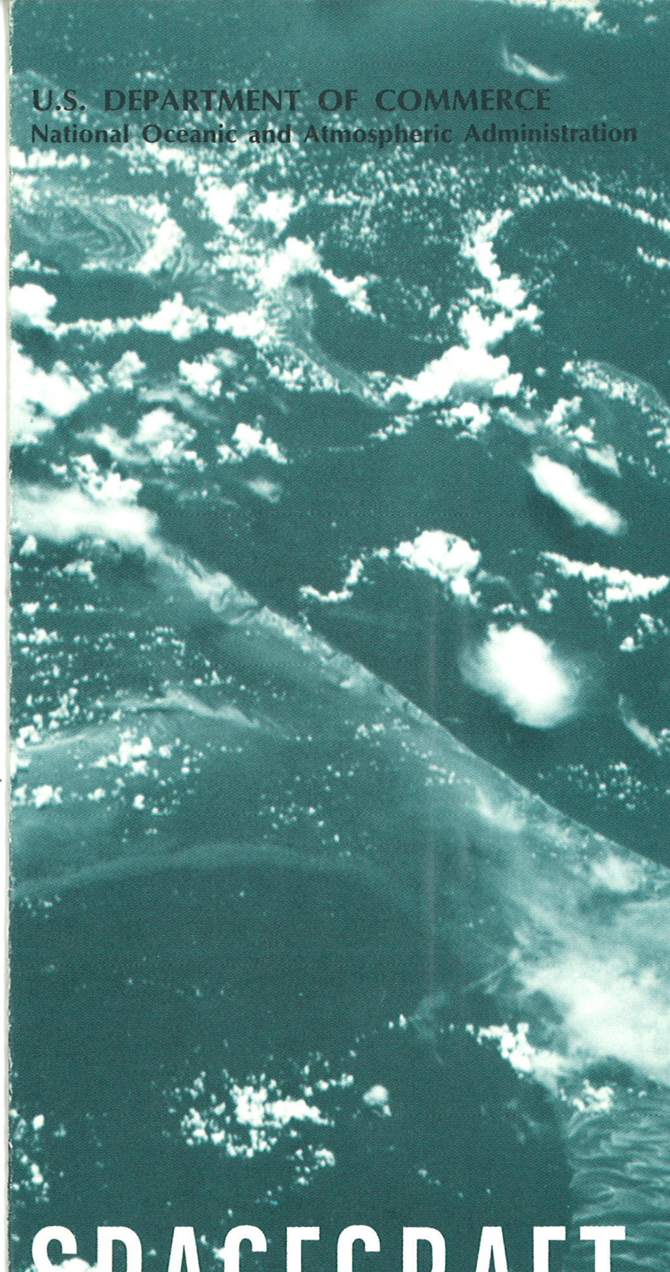
U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration



SPACECRAFT OCEANOGRAPHY

NASA Photo

The effort conducted by NOAA, the U.S. Commerce Department's National Oceanic and Atmospheric Administration, to read oceanic intelligence from satellite data is as old as space technology in this country. Working closely with the National Aeronautics and Space Administration, the U.S. Navy, and other organizations, NOAA has helped bring into operational use a variety of marine products derived from satellite sensors.

Even in the data returned by the first meteorological satellites a decade and a half ago, there was "wet" information—ice could be distinguished from clouds, and, in cloud-free areas, the surface was visible, most of it ocean. Since then, the early promise has been reinforced by the color photography from Gemini, Apollo, and Skylab, and the views of varied sensors aboard NOAA's environmental satellites and the developing earth resources series; and the concept of monitoring marine environmental conditions from above has become a new science—spacecraft oceanography.

Now this work seeks to improve the capabilities of satellites to observe the global ocean and its life, and to improve man's ability to infer oceanic processes and life forms from such clues as water color, temperature, texture, topography, nutrient distributions, and other characteristics that can be observed from satellite altitudes.

Color. Oceanographers and mariners have known for generations that water color offers important clues to ocean depth, weather, and biological activity in the sea. A deep ultramarine blue marks a sterile, clear, open ocean, while increasing amounts of chlorophyll-bearing plankton add to the green and red portions of the spectrum. Sediments tend to be brownish. In shallow water, white seafloor lightens the general color of a region, vegetation darkens it. Such properties of color have been applied by marine cartographers using color aerial photography to contour depths for relatively clear shoal water, and much analysis has been given the color photographs from Gemini and Apollo, which show physical and marine biological detail—for example, areas of upwelling, water mass boundaries, and dispersion patterns of coastal effluents. Various false color enhancement techniques are being applied to emphasize various regions of the ocean wave spectrum, with an eye to monitoring sea state.

ERTS-1 took the next step. Its multispectral scanners, which provide a high-resolution look at the earth's surface from space, sense in four channels (green, red, and two near-infrared). Because water has varying reflectivities in these four channels, each channel penetrates clear water to a different depth, permitting the construction of cross-sectional views of the surface and upper layers of the water mass.

ERTS-1 multispectral data have been used extensively to detect ocean dumping events, measure the distributions of sediments and planktonic life, monitor patterns of energy transmission and reflection in estuaries and embayments, mark the zones where cold water meets warm, fresh meets salt, polluted meets clear. Repeated observations can be used to identify long-term pollution trends, and such short-term ecological catastrophes as major oil spills. The advantages already realized from ERTS, a land-tuned system, suggest that an ocean-tuned multispectral instrument would provide much physical and biological data of value to oceanographers and marine biologists, and a powerful tool with which to work toward balanced use and conservation in the coastal environment.

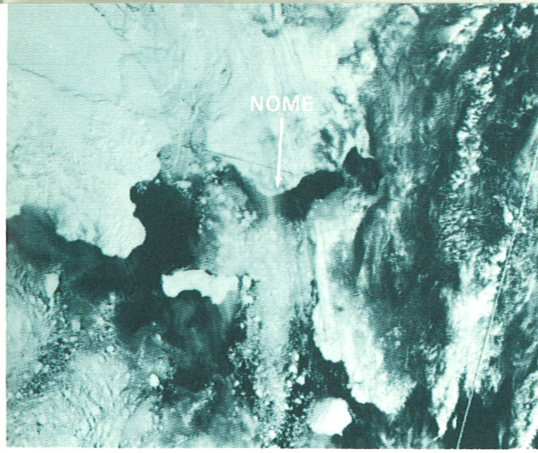
Temperature. Objects at the temperature of the earth and ocean emit energy in the infrared and microwave portions of the spectrum—the wavelengths extending from the longer, invisible side of red into the range of radar wavelengths. These are the regions in which heat can be seen by spacecraft sensors, and the global distributions of heat energy that drive the atmosphere—and, to a lesser extent, the ocean—can be monitored and mapped. In some ways the infrared is the most productive part of the spectrum for satellite sensors. The water in the atmosphere absorbs infrared radiation at most wavelengths, but there are spectral intervals, or "windows", where the cloudfree atmosphere is transparent in the infrared range. This means infrared sensors can measure distributions of heat energy from the upper reaches of the atmosphere to the surface or cloud tops. And infrared sees equally well, day and night.

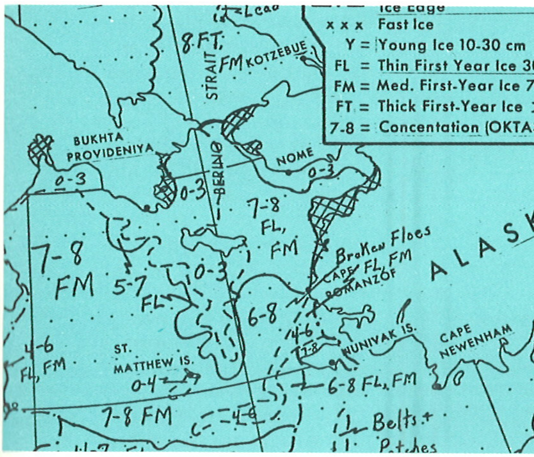
NOAA-2, the second in the present operational environmental satellite series, brought to the routines of meteorology night-and-day infrared scanning of the planet's cloud cover, and vertical temperature soundings of the atmospheric column. For oceanographers, high-resolution radiometers aboard these satellites have brought a revolutionarily improved view of oceanic processes—infrared data from the satellite can be used to measure currents, sea surface temperatures, life-rich areas of upwelling, ice thickness, concentration, and extent, and winter snowpack, where nature stores the waters of spring. High-resolution infrared instruments aboard operational geostationary spacecraft will add virtually real-time continuity to that view of the global ocean.

Texture. Techniques that measure sea surface temperatures in terms of microwave brightness—that is, the intensity of oceanic emissions seen by a sensor observing in the microwave radio frequency range—are less well developed than similar techniques using infrared sensors. The microwave emissions are closely linked to such factors as microwave frequency, thermodynamic temperature, salinity, surface roughness, and foam cover. This complexity, however, has led to a promising family of experimental sensors (flown on aircraft, *Nimbus*, and *Skylab*) that can observe both the temperature and texture of the ocean surface—foam, small-scale roughness, differences between old and new ice, and the like. Microwave sensors can also tell scientists something about such things as snowpack and soil moisture. An additional advantage of microwave sensing is that most cloud systems are transparent to lower microwave frequencies. This holds out the possibility that future satellites may be able to probe for sea state through the cover of maritime storms. Also, microwave systems augmented by infrared sensors can provide sea-surface temperatures beneath the storms. Both types of data would be welcomed by high-seas and polar weather forecasters, whose tasks are greatly complicated by the pervasive clouds which mask atmospheric centers of action.

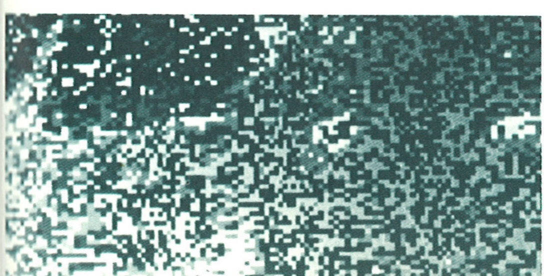
Topography. Much of the earth's surface is covered by water, which is taken to be smoothly spherical, like paint on a billiard ball. But in fact, the ocean surface is a place of shallow valleys and low-lying, watery hills, of currents banked like raceways—there is, for example, about a one-meter change in elevation across the Gulf Stream—and a wide range of topographic detail ranging from tiny capillary waves to the world-sized motions of the tides. For those engaged in the millimeter-per-kilometer accuracies of geodesy, oceanic irregularities are as significant as they are difficult to measure. (The geoid, an imaginary earth-shape described by mass and gravitation relationships and used by geodesists as a reference surface, is the surface gravity would form of a uniform, motionless ocean in which all waves and currents ceased.) For example, the geoidal undulation caused by subterranean mass under the Puerto Rico Trench causes a 15-meter-deep "valley" along the ocean surface above the trench. The global ocean abounds with such gravity-induced wrinkles. Waves, tides, and currents then lead to departures of the sea surface from the geoid that, in principle, can be used to measure those quantities.

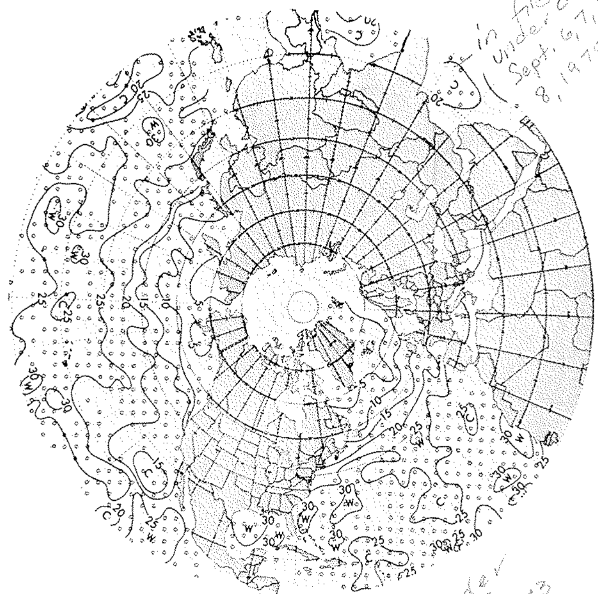
Scientists believe precise altimeters aboard satellites can provide the accuracies required to measure such features as wind-generated gravity waves, storm surges, tsunamis, and ocean tides, and both radar and laser altimeters are being developed for these applications. *Skylab* radar has already observed the "valley" across the Puerto Rico Trench. A short-pulse radar altimeter tested aboard aircraft and *Skylab* is scheduled for use on GEOS-C, a geodetic satellite, and the laser altimeter is being used aboard research aircraft to measure wave heights and other marine topographic features.





Sea-ice monitoring and mapping has been one of the most successful applications of spacecraft oceanography. Since the mid-1960's, personnel at the National Environmental Satellite Service have used satellite data to prepare global analyses of sea-ice, and NOAA-2 VHRR images are being used to prepare special sea-ice maps for the Beaufort and Bering Seas; the products shown here are from this weekly series of maps. The microwave image of Arctic sea ice shown below was obtained through the clouds from a NASA aircraft. Darkest areas are multiyear ice, lightest areas, first-year ice.





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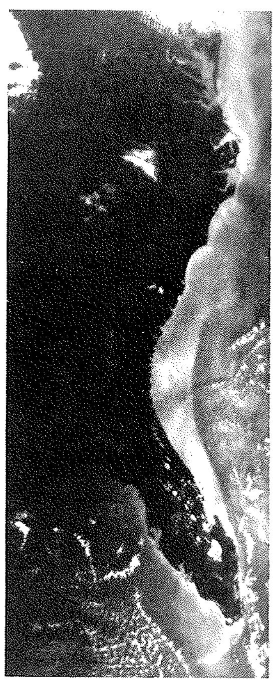
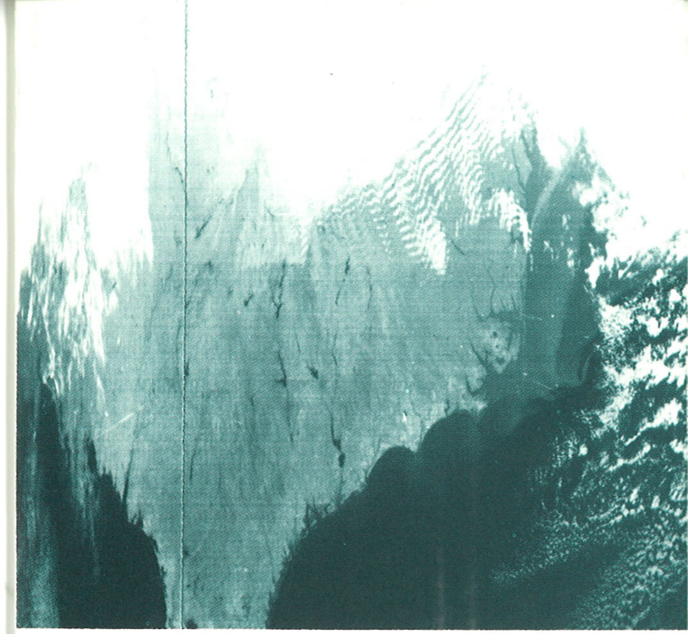
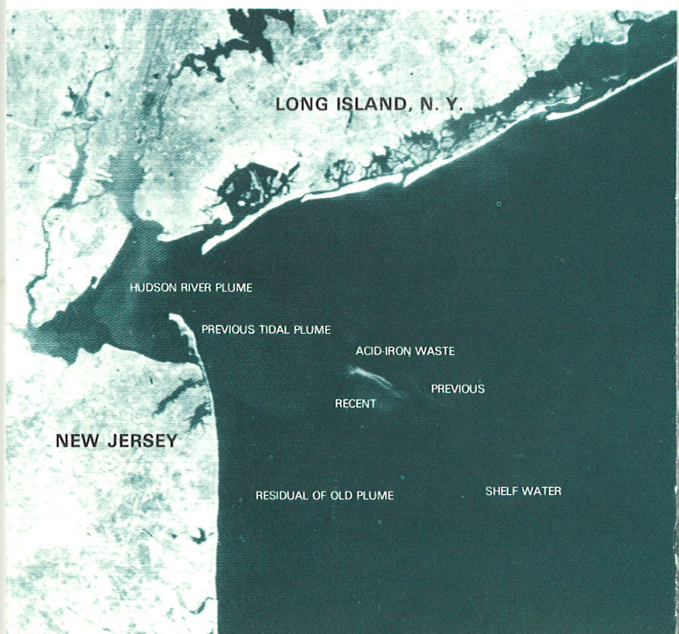
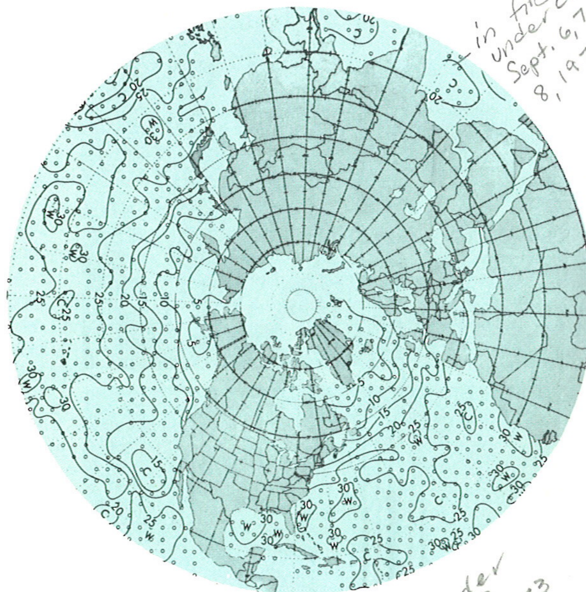




SPACECRAFT OCEANOGRAPHY FROM THE GENERAL TO THE SPECIFIC. Upper left, sea-surface temperatures on a global scale are derived from NOAA satellite data. Below left, features of the U.S. eastern seaboard are picked out by visible and infrared satellite sensors. Above, an image from NOAA-2's very-high-resolution infrared radiometer shows the Gulf Stream (darker area). Below, an ERTS-1 image of the New York Bight yields marine environmental information.





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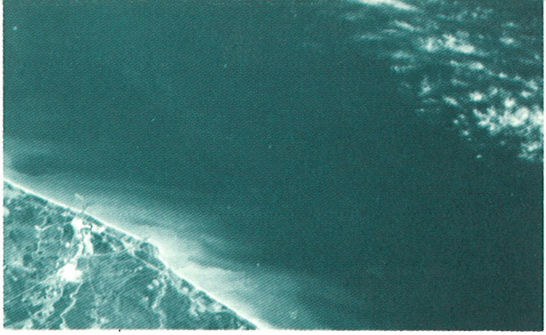

NOAA's spacecraft-oriented activities are conducted by the National Environmental Satellite Service, which, from a headquarters near Washington, D.C., and satellite data acquisition stations in Alaska and Virginia, operates the polar-orbiting NOAA satellites and geostationary satellite system. It is also a prime mover in developing new uses of satellite data, and new directions in spacecraft and sensor technology.

The ocean-looking side of NOAA's satellite effort is more diffuse, being centered in four major elements within the agency: The Spacecraft Oceanography and Environmental Sciences Groups of the National Environmental Satellite Service; the Ocean Remote Sensing Laboratory of the Atlantic Oceanographic and Meteorological Laboratories (part of the Environmental Research Laboratories); the Fisheries Engineering Laboratory of the National Marine Fisheries Service; and the Office of Marine Surveys and Maps of the National Ocean Survey.

These mutually complementary efforts approach spacecraft oceanography from different directions. Scientists with the National Environmental Satellite Service are primarily concerned with making present and future operational satellites (including any purely oceanographic ones) and their sensors better serve the broad environmental mission of NOAA, and this objective guides their oceanic efforts. The Atlantic laboratory, on the other hand, deals mainly with developing innovative, oceanic applications of available satellite data products, and contributing to national plans for ocean-dedicated satellites. The fisheries scientists are interested in using satellites and new sensors to improve the ways in which we harvest and conserve the living resources of the sea. The ocean surveyors are developing techniques for using satellite data in reconnaissance studies of currents and other features of the coastal zone.

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